APPENDIX D

PROCEDURES FOR THE DISINFECTION OF WATER MAINS

All new or repaired potable water lines in a public water supply system must be disinfected with free chlorine before they are put into service (KAR 28-15-18(d)). These disinfection procedures are based on the AWWA Standard for Disinfecting Water Mains, AWWA C651. The most recent revision of the standard shall apply. A copy of the complete standard is available for review at the KDHE office, Curtis State Office Building, 1000 Jackson St., Suite 420, Topeka, KS. A copy of the standard may be obtained from the American Water Works Association, 6666 West Quincy Avenue, Denver, Colorado, 80235.

NON-EMERGENCY PROCEDURES FOR THE DISINFECTION OF WATER MAINS

There are five basic steps for the non-emergency disinfection of water mains. The first step is to protect the water main's sanitary condition. It is always best to prevent the introduction of contaminated material into water main pipe, especially during its installation. However, whenever this is not possible, any contamination that does occur must be either flushed from the water main or removed by other more direct methods prior to disinfection. When the water main has been adequately cleared, it may then be disinfected by either the tablet, continuous or slug method of disinfection. These methods disinfect by maintaining a minimum period of contact between the water main and the disinfecting solution prepared and delivered as prescribed below for each method. In addition, each method requires flushing of the heavily chlorinated disinfecting solution followed by its proper disposal in a manner that does not adversely impact the environment. The final step consists of collecting samples from the water main for bacteriological testing as a means to confirm the effectiveness of the disinfection procedure. While this method of confirmation is not required, KDHE strongly recommends that this final step be completed.

Step 1: Preventative Measures During Construction

During construction, the interior as well as all sealing surfaces of pipes, fittings, and accessories should be kept clean as possible. Inspect the interior of all pipes prior to installation. If dirt enters the pipe, it should be removed and the affected interior of the pipe swabbed with a 1 percent free available chlorine solution. All openings in pipelines should be closed with watertight plugs whenever the trench is unattended. Sealing, lubricating, or gasket materials used in pipe installation should be stored and handled in a manner that avoids contamination and keeps them suitable for use with potable water.

Step 2: Preliminary Flushing of Mains

Before being chlorinated, the main should be completely filled with water to eliminate air pockets and then flushed to purge the line of dirt and debris. This is typically done after the completion of the leakage and pressure tests. Incomplete removal of dirt and debris from lines prior to disinfection often leads to failed bacteriological tests, requiring repeated disinfection. Preliminary flushing should be accomplished at a rate of at least 2.5 ft/sec. Fittings and valves should be thoroughly cleaned before applying chlorine to a main. Special attention should be given to mechanical joints, fittings, and valves that may contain spaces that are difficult to chlorinate once they become filled with water.

Table 1 shows the required flow rate to obtain a velocity of 2.5 ft/sec in commonly used sizes of pipe. Flushing can be enhanced by the use of soft pigs to remove dirt, debris, and air from the main prior to disinfection. The use of pigs can also conserve water and is particularly useful when there is insufficient water supply to attain a 2.5 ft/sec minimum flushing velocity.

TABLE 1 - FLOWS REQUIRED FOR VARIOUS FLUSHING VELOCITIES

Pipe Size	**Pipe Area**	**Flow Required (gpm) for Given Velocity**		
(in)	**(sq ft)**	**1 ft/sec**	**2.5 ft/sec**	**5 ft/sec**
2	0.02	10	25	50
4	0.09	40	100	200
6	0.20	90	220	440
8	0.35	155	390	780
10	0.55	245	610	1,220
12	0.79	350	880	1,760
14	1.07	480	1,200	1,400
16	1.40	625	1,570	3,140

Preliminary flushing, however, should not be conducted if tablets or granules of calcium hypochlorite have been placed in the pipe during installation. In this case, special care must be exercised in ensuring that the main does not become contaminated with dirt or other materials during construction.

Step 3: Chlorination of Mains

Disinfection of mains should be done only by crews who have had experience with chlorinating agents, who are aware of the potential health hazards associated with these chemicals, and who are trained to carefully observe proper construction and disinfection practices.

Chemical Forms of Chlorine

Chlorine is generally available in three chemical forms: gaseous (elemental) chlorine (shipped as a liquefied gas); in solution (sodium hypochlorite); and as a solid (calcium hypochlorite tablets or granules). The gaseous form may only be applied with feed systems that operate under vacuum, the solution form is generally diluted, and the solid form must be dissolved.

A. Gaseous Chlorine

Gaseous chlorine is generated from the controlled vaporization of liquid chlorine supplied in 100 or 150-lb steel cylinders through a vacuum-operated chlorinator with a booster pump. The vacuum-operated chlorinator injects chlorine gas into water to form a solution; the booster pump introduces the solution into the main to be disinfected. Direct-feed chlorinators, which operate solely from gas pressure in the chlorine cylinder, are not approved for use due to the danger of chlorine release. Gaseous chlorine application should only be conducted under the direct supervision of a trained operator and in accordance with the safety standards and practices described in Chapter IX of KDHE's "Policies, General Considerations and Design Requirements for Public Water Supply Systems in Kansas."

B. Sodium Hypochlorite

Sodium hypochlorite is available as a liquid in 1 quart to 5 gallon containers and contains approximately 5 to 15 percent available chlorine. ANSI/NSF 60 certified household bleaches typically contain approximately 5.25 percent available chlorine. The availability of household bleaches having NSF International's ANSI/NSF 60 certification varies from market to market. Special precautions must be taken to minimize deterioration of sodium hypochlorite solutions in storage.

C. Calcium Hypochlorite (HTH)

Calcium hypochlorite (HTH) is available in granular and tablet forms typically containing approximately 65 percent available chlorine. The granules dissolve readily in water; however, the tablets can be more difficult to dissolve. In contrast to sodium hypochlorite, calcium hypochlorite can be stored for extended periods of time without significant deterioration. Contact with organic material or high temperatures must be avoided due to the danger of fire or explosion.

Methods of Chlorination

AWWA Standard C651 provides for three methods of chlorination for water mains: tablet, continuous, and slug. The chlorine dose and minimum contact time for each AWWA method are summarized in Table 2. Recommendations for disinfection of small sections of mains under emergency repair are also included in Table 2. Methods for measurement of free chlorine residual are summarized in Attachment A. Before any disinfection method is utilized, valves must be positioned so that the highly chlorinated water in the main being treated does not flow into water mains that are in active service.

TABLE 2 - CHLORINATION METHODS FOR DISINFECTING WATER MAINS

Chlorination Method Used	Initial Chlorine Dose (mg/L)	Minimum Contact Time (hours)	Minimum Chlorine Resid. (mg/L)
Nonemergency Procedures			
Tablet	25	24	10
Continuous	25	24	10
Slug	100	3	50
Emergency Procedures			
Premixed Solution or Hypochlorite Injection	300	0.25	100
Swabbing	10,000 (1% sol)	---	Swab throughly the interior of pipes and fittings used in repairs.

Factors to consider when choosing a method of chlorination include length and diameter of the main, types of joints present, equipment and materials necessary for disinfection, skills and training of personnel, safety concerns, and if the main must be quickly put into service. The continuous and slug methods require the use of appropriate chlorine feed equipment and the determination of the necessary chlorine feed rate for the chlorine solution. In long, large-diameter mains, the slug method has the potential for reducing the volume of water and amount of chemicals needed as compared to the continuous method.

The tablet method is convenient to use for mains with diameters less than 24 inches and does not require special chlorine feed equipment. There are, however, important limitations with this method. The tablet method precludes preliminary flushing which is often necessary to remove dirt and debris and assist in the removal of air from the lines. Calcium hypochlorite granules or tablets may be dislodged from the lines during filling and accumulate at points of restriction leaving portions of the line without disinfectant. The tablet method should not be used in large diameter mains, where a worker might enter the main for inspection, due to the potential for tablets to release toxic fumes.

A. Tablet Method

The tablet method consists of pre-placing calcium hypochlorite granules or tablets in the main during pipe installation in sufficient amounts so as to obtain a 25 mg/L available chlorine dose. For calcium hypochlorite granules, they should be placed at the upstream end of the first section of pipe, at the upstream end of each branch main, and at 500 ft.

intervals. Additionally, one tablet should be placed in each hydrant, hydrant branch, and other appurtenances. For 65 percent available chlorine, the quantities of granules necessary for a 25 mg/L chlorine dose are listed in Table 3 as a function of pipe diameter.

TABLE 3 - AMOUNTS OF CALCIUM HYPOCHLORITE GRANULES TO BE PLACED AT 500-ft INTERVALS FOR 25 mg/L FREE CHLORINE DOSE

Pipe Diameter (in)	Calcium Hypochlorite Granules (65% available) (ounces)	(grams)
2	0.4	12
4	1.7	47
6	3.8	107
8	6.7	190
10	10.5	297
12	15.1	427
16	26.8	760

Adapted from AWWA Standard C651-05

Calcium hypochlorite granules should not be placed in the pipe so as to come in contact with exposed joint compounds, such as those used on solvent-welded plastic pipe, because of the danger of fire or explosion from the reaction of the joint compound with the calcium hypochlorite.

Instead of granules, calcium hypochlorite 5-g tablets can be attached with a food-grade adhesive to the top inside surface of each section of the main's pipe. Table 4 shows the number of 5-g tablets required for commonly used pipe sizes.

After installation is complete, the main should be filled with potable water at a velocity no greater than 1 ft/sec (See Table 1 for flow rates corresponding to 1 ft/sec velocity for standard pipe sizes.). The chlorinated water must be maintained in the main for at least 24 hours. If the water temperature is less than 41°F (5°C), the water should remain in the pipe for at least 48 hours. At the end of the minimum contact period, the treated water in all portions of the main must have a residual of not less than 10 mg/L free chlorine as confirmed by measurement of the chlorine residual. Methods utilized to measure free chlorine residual are discussed in Attachment A.

TABLE 4 - NUMBER OF 5-g CALCIUM HYPOCHLORITE TABLETS REQUIRED FOR DOSE OF 25 mg/L*

Pipe Diameter (in)	Length of Pipe Section, ft: 13 or less	18	20	30	40
	Number of 5-g Calcium Hypochlorite Tablets				
2	1	1	1	1	1
4	1	1	1	1	1
6	1	1	1	2	2
8	1	2	2	3	4
10	2	3	3	4	5
12	3	4	4	6	7
16	4	6	7	10	13

*Based on 3.25-g available chlorine per tablet; any portion of tablet rounded to the next highest interger. (Adapted from AWWA Standard C651-05)

B. Continuous Method

Though this method is referred to as "continuous," it does not require continuous feeding of chlorine into the main over a 24 hour period. The key feature is that the main is "continuously" in contact with at least 10 mg/L free chlorine concentration over 24 hours with an initial dose of 25 mg/L. Two procedures will be outlined below.

Procedure 1: Addition of Pre-mixed Chlorinated Water

In this procedure, hypochlorite is added to potable water in a tanker truck or other large container in sufficient volume to completely fill the main with a chlorine residual of 25 mg/L. The chlorinated water from the tanker truck or large container is then pumped into the main until full as indicated by a discharge through a terminal outlet such as a hydrant. The addition of premixed chlorinated water to the main does not require the feeding of a concentrated chlorine solution or the measurement and control of the filling rate and the chlorine solution injection rate.

The minimum amount of calcium hypochlorite (HTH) required for a 25 mg/L chlorine dose can be calculated from the known volume of the main that is to be disinfected:

$$\frac{Vol_{main,}gal * \frac{1\ MG}{1 \times 10^6 gal} * 8.34\ \frac{lb}{gal} * 25\ \frac{mg}{L}}{\frac{(\%\ available\ Cl_2)}{100}} = \text{minimum lbs of HTH available} \quad \text{(Eq. 1)}$$

where,

Vol_{main} = volume of main, gal
= length(ft) * π[dia(ft)]^2/4 * 7.48 gal/ft^3

Please note that the units in the above equation (Eq. 1) will correctly cancel provided one recognizes that there are one million mg in one liter (10^6 mg/liter) and that % available Cl_2/100 is equal to lbs of chlorine per lb of HTH (lb Cl_2/lb HTH).

The following equation determines the necessary amount of sodium hypochlorite to achieve a 25 mg/L chlorine dose in a given main:

$$\frac{Vol_{main} * 25\ \frac{mg}{L}}{Conc_{soln}\ \frac{mg}{L}} = Vol_{soln} \quad \text{(Eq. 2)}$$

where,

Vol_{main} = volume of main, gal
$Conc_{soln}$ = concentration of chlorine in sodium hypochlorite solution, mg/L as Cl_2
Vol_{soln} = volume of sodium hypochlorite solution, gal

The quantities of 15 percent available chlorine sodium hypochlorite or 65 percent available chlorine calcium hypochlorite (HTH) required to produce a 25 mg/L concentration in water filling a section of main with a length of 100 ft. in common diameters are shown in Table 5.

Procedure 2: Injection of Concentrated Chlorine Solution

An alternate approach is to inject a concentrated chlorine solution into the main while it is being filled. The contractor or operator maintains a desired water flow rate while filling the main through an inlet valve on a temporary connection to the existing distribution system or other approved source. At a point no more than 10 ft. downstream from the inlet to the main, the concentrated chlorine solution is pumped into the main at a uniform feed rate until the desired chlorine residual (at least 25 mg/L) is measured in the flushed water at the terminal outlet (Figure 1). The main is then shut down and the chlorinated water allowed to stand in the pipe for a 24 hour period. At the end of this time period, the treated water in the main should have a chlorine residual of not less than 10 mg/L free chorine in all portions of the main as confirmed by the measurement of the chlorine residual in samples collected from the main. Methods utilized to measure free chlorine residual are discussed in Attachment A.

TABLE 5 - HYPOCHLORITE REQUIRED TO PRODUCE 25-mg/L DOSE IN 100 ft OF PIPE

		Hypochlorite Solution				Granules
	Total	Percent Available Chlorine				
Pipe Size (in)	Pipe Volume (gal)	1-percent (gal)	5-percent (gal)	10-percent (gal)	15-percent (gal)	65-percent (ounces)
2	16.3	0.041	0.0082	0.0041	0.0027	0.084
4	65.3	0.16	0.033	0.016	0.011	0.34
6	147	0.37	0.073	0.037	0.024	0.75
8	261	0.65	0.13	0.065	0.044	1.3
10	408	1.02	0.20	0.10	0.068	2.1
12	587	1.47	0.29	0.15	0.098	3.0
16	1044	2.61	0.52	0.26	0.17	5.4

Note: 1-percent chlorine solution = 10,000 ppm or mg/L free chlorine.

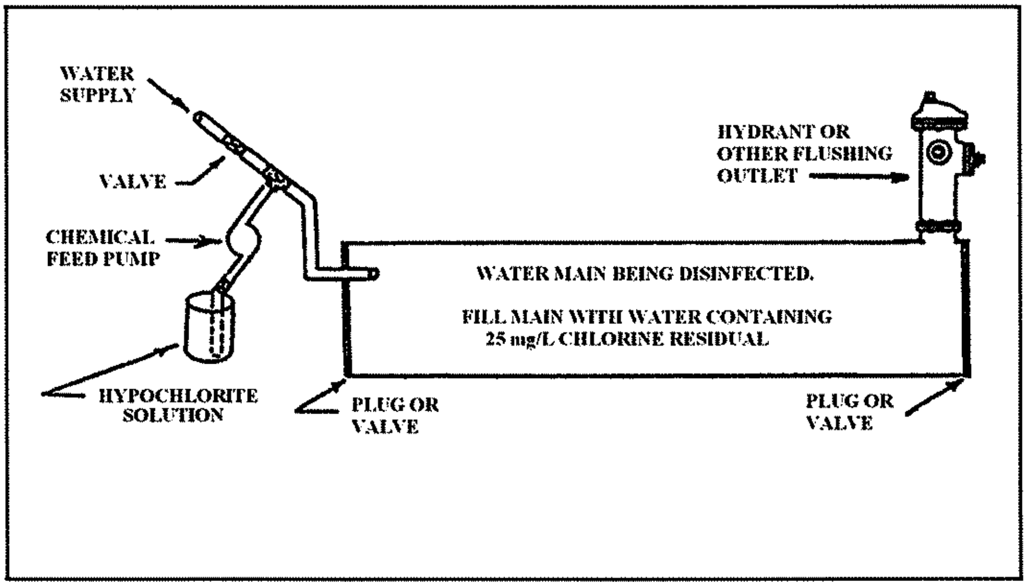

Figure 1 - TYPICAL HYPOCHLORITE INJECTION SYSTEM

The concentrated chlorine solution may be prepared from calcium or sodium hypochlorite and injected into the main with a chemical feed pump designed for chlorine solutions. While this is readily accomplished with sodium hypochlorite because it is purchased as a liquid, calcium hypochlorite in the form of HTH granules or tablets must first be dissolved in water. It is important to remember that the HTH granules or tablets should be added to the correct volume of water in order to adequately disperse the heat generated during dissolution, rather than adding water to the HTH granules or tablets. Feed lines and connections should be of such material and strength as to safely withstand the corrosive effect of the concentrated chlorine solution and the pressure of the pump. The flows of both the water filling the main and the concentrated chlorine solution being injected must be proportioned so that the resulting chlorine concentration in the main is uniform and at least 25 mg/L (Figure 2).

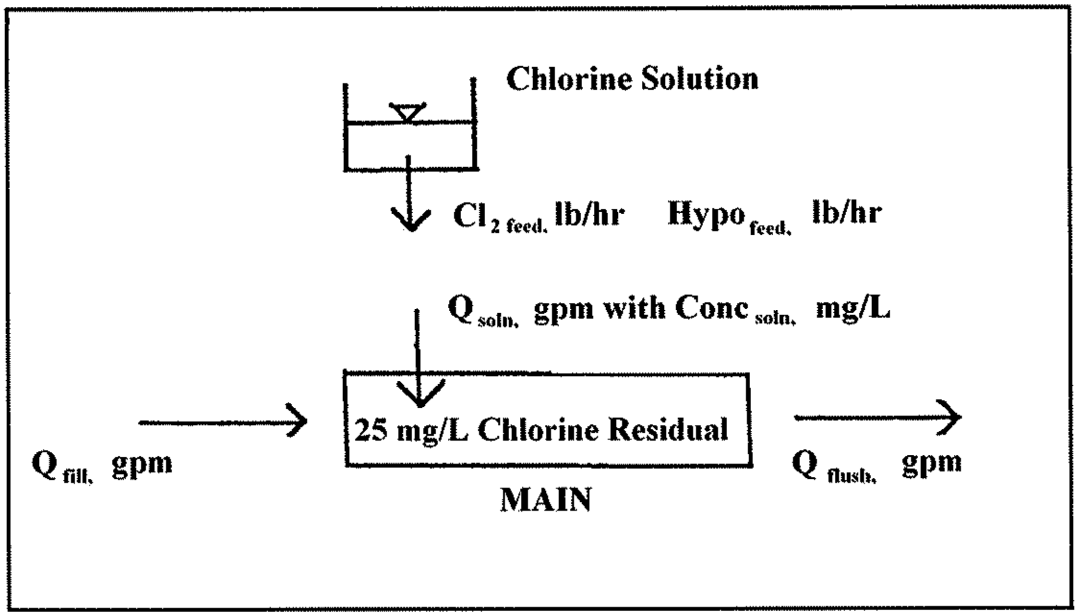

Figure 2 - MASS BALANCE DIAGRAM FOR Cl_2 SOLUTION INJECTION

In most cases, the chlorine solution injection rate, Q_{soln}, will be significantly less than the rate of filling the main, Q_{fill}. When this is true, Q_{fill} may be considered essentially equivalent to the rate of water exiting the main, Q_{flush}. After startup of the chlorine solution injection, the chlorine residual should be checked at the first available outlet, and the hypochlorite injection rate adjusted to obtain a residual of at least 25 mg/L.

This approach, the injection of a concentrated chlorine solution into a flowing main, is consistent with the typical chlorination procedure used by operators in disinfecting a continuous flow of water from a well using a hypochlorite feed system. It does, however, require maintaining a specific main filling rate (or flushing rate from the outlet of the pipe) as well as a uniform chlorine solution injection rate. Flow rates may be difficult to measure accurately under field conditions that typically involve temporary connections. In addition to the use of flow meters, methods for estimating flow rates include measuring the time to fill a container of known volume or measuring the trajectory of the discharge from a hydrant and using the formula in Figure 3 to determine the flow rate.

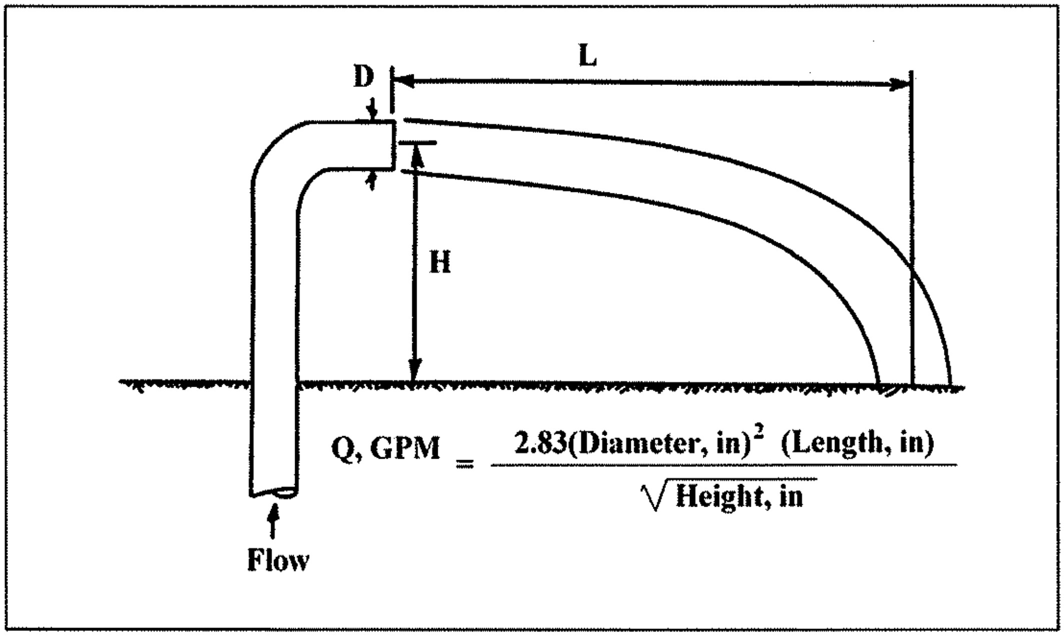

Figure 3 - FORMULA FOR ESTIMATING RATE OF DISCHARGE
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The chlorine feed rate into the main, $Cl_{2\ feed}$, for a 25 mg/L dose (assuming 100 percent available chlorine such as supplied by chlorine gas) may be calculated with the following equation:

$$Q_{fill}, \frac{gal}{min} * 1440\frac{min}{day} * \frac{1\ day}{24\ hr} * \frac{1\ MG}{1 \times 10^6 gal} * 8.34\frac{lb}{gal} * 25\frac{mg}{L} = Cl_{2\ feed}, \frac{lb}{hr} \qquad \text{(Eq. 3)}$$

where,

Q_{fill} = flow rate of water filling main, gpm
$Cl_{2\ feed}$ = chlorine feed rate into main, lbs of Cl_2 as 100% available chlorine /hr

In chlorine feed rate problems, the chlorine solution injection rate, Q_{soln}, and the filling rate of the main, Q_{fill}, are typically assumed and fixed. Where the chlorine solution is applied uniformly to the main while it is filling, the time of filling of the main, T_{fill}, is essentially equivalent to the time of chlorine solution injection, $T_{injection}$:

$$\frac{Vol_{main}, gal}{Q_{fill}, \frac{gal}{min}} = T_{fill}, min = T_{injection}, min \qquad \text{(Eq. 4)}$$

where,

Vol_{main} = volume of main, gal
Q_{fill} = main filling rate, gpm
T_{fill} = time to fill main, min
$T_{injection}$ = time of chlorine solution injection, min

The minimum volume of chlorine solution, prepared from either sodium or calcium hypochlorite, may be determined by multiplying the chlorine solution injection rate by the time of chlorine solution injection:

$$Q_{soln}, \frac{gal}{min} * T_{injection}, min = Vol_{soln}, gal \qquad \text{(Eq. 5)}$$

where,

Q_{soln} = rate of chlorine solution injection, gpm
$T_{injection}$ = time of chlorine solution injection, min
Vol_{soln} = volume of chlorine solution, gal

Utilization of Calcium Hypochlorite (HTH)

When calcium hypochlorite is utilized to prepare a concentrated chlorine solution for this second procedure, the chlorine solution feed rate, $Cl_{2\,feed}$ (lb/hr) (Eq. 3), can be converted to a calcium hypochlorite feed rate (HTH), HTH_{feed} (lb/hr) by use of the following equation:

$$\frac{Cl_{2\,feed}, \frac{lb}{hr}}{\frac{(\%\ available\ Cl_2)}{100}} = HTH_{feed}, \frac{lb}{hr} \qquad \text{(Eq. 6)}$$

The total lbs of calcium hypochlorite required for disinfecting a given main are determined by multiplying HTH_{feed}, (lb/hr) by the injection time, $T_{injection}$, expressed in units of hours or by solving Eq. 1 above:

$$HTH_{feed}, \frac{lb}{hr} * T_{injection}, hr = \text{ minimum required HTH, lbs} \quad \text{(Eq.7)}$$

where,

HTH_{feed} = calcium hypochlorite feed rate, lb/hr
$T_{injection}$ = time of chlorine solution injection, hr

The concentration of the chlorine solution, prepared by the addition of the required lbs of HTH to the necessary volume of water, Vol_{soln} (Eq. 5), may be calculated by use of the following equation:

$$\frac{\text{lbs of HTH}}{Vol_{soln}, gal} * \frac{(\text{\% available } Cl_2)}{100} * \frac{1 \times 10^6}{1\ MG} * \frac{1\frac{mg}{L}}{8.34\frac{lb}{MG}} = Conc_{soln}, \frac{mg}{L} \quad \text{(Eq. 8)}$$

where,

Vol_{soln} = volume of chlorine solution, gal
$Conc_{soln}$ = chlorine concentration in injected solution, mg/L as Cl_2

Utilization of Sodium Hypochlorite Solution

A concentrated sodium hypochlorite solution may also be utilized for this second procedure. Sodium hypochlorite is available in liquid form as a concentrated chlorine solution expressed typically in percent available chlorine where 1 percent available chlorine is approximately equivalent to 10,000 mg/L chlorine. Strong solutions of sodium hypochlorite, such as 15 percent, may be injected directly into a flowing main with a chemical feed pump without the necessity of dilution. In such cases, the concentration of chlorine in the injected solution is known. For an assumed sodium hypochlorite solution injection rate, Q_{soln}, the filling rate of the main, Q_{fill}, can be determined from the following equation:

$$\frac{Q_{soln} * Conc_{soln}, \frac{mg}{L}}{25\frac{mg}{L}} - Q_{soln} = Q_{fill} \quad \text{(Eq. 9)}$$

where,

Q_{soln} = rate of sodium hypochlorite solution injection, gpm
$Conc_{soln}$ = chlorine concentration in injected solution, mg/L as Cl_2
Q_{fill} = main filling rate, gpm

Table 5 includes the minimum volumes of various sodium hypochlorite solutions (1%, 5%, 10%, and 15%) for direct injection into a 100 ft. main to prepare a 25 mg/L chlorine dose. Eq. 2 above may also be used to calculate the required volume of chlorine solution as sodium hypochlorite for a given Vol_{main}, Q_{fill}, and Q_{soln}. For a given Q_{fill}, Eq. 3 above may be utilized to calculate the necessary chlorine feed rate into the main, which is converted to a sodium hypochlorite feed rate by the following equation:

$$\frac{Cl_{2\,feed}, \frac{lb}{hr}}{\frac{(\%\text{ available } Cl_2)}{100}} = \text{Na} - \text{hypo}_{feed}, \frac{lb}{hr} \qquad \text{(Eq. 10)}$$

where,

$Cl_{2\ feed}$ = chlorine feed rate into main, lbs of Cl_2 as 100% available chlorine /hr
Na-hypo$_{feed}$ = rate of sodium hypochlorite solution injection, lb/hr

If a flow rate in gal/hr is more convenient, then the sodium hypochlorite feed rate can be determined by the following equation:

$$\frac{Cl_{2\,feed}, \frac{lb}{hr}}{\frac{(\%\text{ available } Cl_2)}{100} * 8.34\frac{lb}{gal}} = \text{Na} - \text{hypo}_{feed}, \frac{gal}{hr} \qquad \text{(Eq. 11)}$$

where,

$Cl_{2\ feed}$ = chlorine feed rate into main, lbs of Cl_2 as 100% available chlorine /hr
Na-hypo$_{feed}$ = rate of sodium hypochlorite solution injection, gal/hr

If a sodium hypochlorite solution must be diluted with water to prepare for injection into a main a given volume of a solution having a lower chlorine concentration (e.g., diluting a 15 percent available chlorine solution to form a 5 percent available chlorine solution), then the following equation may be used to determine the volume of concentrated sodium hypochlorite required:

$$\frac{(\text{gal dilute soln}) * (\%\text{ available } Cl_2 \text{ dilute soln})}{(\%\text{ available } Cl_2 \text{ concentrated soln})} = \text{gal concentrated soln} \qquad \text{(Eq.12)}$$

C. Slug Method

The slug method consists of the formation of a slug of chlorinated water in the main with a free chlorine concentration of at least 100 mg/L. The slug of highly chlorinated water must flow through the main at a slow enough rate so that all parts of the main and its appurtenances will be exposed to the highly chlorinated water for a period of at least 3 hours. As the slug moves through the main, all valves must be fully operated to ensure complete disinfection. This method would be appropriate for long, large diameter mains where the continuous feed method would be impractical. It could also be used for smaller mains of limited length where the continuous method's requirement of 24 hours of contact time cannot be satisfied. By application of a solution having a higher initial chlorine dose, 100 mg/L, the required minimum contact time may be reduced from 24 hours to 3 hours.

The slug of chlorinated water is typically formed through the application of gaseous chlorine, although hypochlorite solutions, purchased as premixed or mixed on site, could also be employed. For relatively small mains, hypochlorite could be added to potable water in a tanker truck or a large container such that the chlorinated water would have an initial concentration of at least 100 mg/L free chlorine. The chlorinated water from the tanker truck or large container could then be pumped into a section of the main until full as indicated by a discharge from the outlet at the other end of the section of main being repaired.

The free chlorine residual must be regularly measured in the slug during the required minimum 3 hours of contact time. If at any time, the free chlorine residual in the slug drops below 50 mg/L, additional chlorine must be applied to the head of the slug in order to reestablish the level of free chlorine in the slug to be at least 100 mg/L.

Step 4: Final Flushing of Mains

After the appropriate minimum retention period, highly chlorinated water should be flushed from the main until chlorine residual measurements show that the chlorine concentration of the water leaving the repaired section of main is no higher than that generally prevailing in the distribution system. Care must be exercised when disposing of water with excessive chlorine residuals. Chlorine is toxic to fish and other aquatic life. Disposal of chlorinated water into storm sewers without prior neutralization of the chlorine residual should be avoided if residual chlorine will still be present when the water directly or indirectly reaches a stream, river, or lake.

Neutralization of the chlorine residual remaining in the water can be accomplished by application of a de-chlorination chemical to the highly chlorinated water in a temporary retention pond, container, or tanker truck. Typical de-chlorination chemicals employed are sulfur dioxide (SO_2), sodium bisulfite ($NaHSO_3$), sodium sulfite (Na_2SO_3), and sodium thiosulfate ($Na_2S_2O_3 \cdot 5H_2O$). The amounts of these chemicals required to neutralize various residual chlorine concentrations in 100,000 gallons of water are listed in Table 6. While the application of de-chlorination chemicals to highly chlorinated waters quickly reduces the level of free available chlorine, significant reductions can also be achieved by exposure of these waters to sunlight in open ponds or in containers. Note that over-feeding a de-chlorination chemical can deoxygenate the receiving water, so the de-chlorination process must be carefully controlled.

TABLE 6 - AMOUNTS OF CHEMICALS REQUIRED TO NEUTRALIZE VARIOUS RESIDUAL CHLORINE CONCENTRATIONS IN 100,000 GALLONS OF WATER

Residual Chlorine Concentration (mg/L)	Chemical Required			
	Sulfur Dioxide (lb)	Sodium Bisulfite (lb)	Sodium Sulfite (lb)	Sodium Thiosulfate (lb)
1	0.8	1.2	1.4	1.2
10	8.3	12.5	14.6	12.0
25	20.9	31.3	36.5	30.0
50	41.7	62.6	73.0	60.0

Adapted from AWWA Standard C651-05.

Step 5: Bacteriological Testing (Optional)

AWWA Standard C651 requires that after the final flushing two consecutive sets of bacteriological samples within a 24 hour period be collected from the new main. At least one set of samples shall be collected from every 1200 ft. of the new main, one set from the end of the line and at least one set from each branch. The samples are tested for the presence of coliform organisms in accordance with *Standard Methods for the Examination of Water and Wastewater* (APHA *et al.*, 2005). KDHE does not require bacteriological testing of new mains but recommends such tests to confirm the effectiveness of the disinfection procedure. It is not uncommon for a public water supply system to require bacteriological testing of mains as part of their standard specifications for the installation of water mains. Unless the provisions of AWWA Standard C651 are incorporated by reference in the system's specifications, the specifications for bacteriological testing should provide: the type, number, and frequency of samples for bacteriological tests; the method of initial sample collection to include repeat sample collection; the party or parties responsible for testing; and the laboratory selection requirements.

Attachment B to this appendix provides a brief summary of bacteriological sampling procedures and analytical methods; however, the most current procedures and methods as outlined in the drinking water regulations should always be employed.

EMERGENCY WATER MAIN DISINFECTION PROCEDURES

When repairs require that mains be opened and depressurized under emergency conditions such as a break or other physical failure of the pipeline, the necessity of restoring water service as soon as possible prevents complete compliance with the routine main disinfection procedures of AWWA Standard C651. Alternate disinfection procedures under such conditions are described in more detail in an article published by Scoot R. Yoo in OPFLOW (Yoo, 1986). The following recommended disinfection procedure is based in part on the article.

The entry of contaminants into the repaired main should be minimized. When feasible, employ clamps, sleeves or other devices to avoid having to take the main out of service and to depressurize it to make the necessary repairs. If the main must be taken out of service and depressurized while repairs are being made it is important that excavated areas be dewatered to the extent practical to prevent dirty water from contacting or entering the pipe. When a pipe is cut and a section removed, the inside of the remaining pipe ends must be examined and pieces of pipe, scale, or other debris removed. Temporary plugs for all open ends of pipes must be provided.

If the main must be depressurized and opened, then the pipe should be disinfected by swabbing it with a concentrated chlorine solution and then thoroughly flushed upon completion of repairs. Alternatively, a high chlorine residual should be maintained in the repaired section of the main for an appropriate period of time. The swabbing method is quick and is generally effective under repair conditions that do not pose a threat of significant contamination. The swabbing method, however, should not be utilized where there is a potential for significant contamination of the main, e.g., when sewage is detected in the trench during repairs.

Swabbing Method

All new pieces of pipe, couplings, clamps, sleeves, and other materials used in the repair must be thoroughly swabbed with a concentrated (1 percent available chlorine or greater) chlorine solution to disinfect all surfaces which will come in contact with potable water. The concentrated chlorine solution may be prepared by adding 2 oz of calcium hypochlorite (65 percent available chlorine) or 26 fl oz of household bleach (5 percent available chlorine) to 1 gallon of water. Clean rags or a sprayer are typically employed to apply the concentrated chlorine solution. Longer pieces of pipe may be disinfected using a clean mop. Proper personal protection such as rubber gloves and goggles should be worn. Respiratory protection equipment should also be worn when ventilation is inadequate.

Hypochlorite Injection or Addition of Pre-mixed Solution

In both of these methods of disinfection, the repaired section of main is briefly contacted with chlorinated water that will have high chlorine residual.

Preliminary Steps

Both methods require the repaired section of main to be isolated from the distribution system. This will require that all service connections along the section of main to be disinfected be shut off. Temporary connections for filling the main with water as well as a method of flushing the main through a hydrant or other temporary outlet must be provided. The isolated section of main must be initially flushed to remove dirty water, debris, and air.

Hypochlorite Injection

In the hypochlorite injection method, liquid sodium hypochlorite is injected into the flowing main by means of a chemical feed pump to establish a high chlorine residual in the repaired section of the main (Figure 1). The initial required chlorine dose is 300 mg/L, verified by measuring the chlorine residual in the water flushed out through an outlet in the other end of the repaired section. The minimum amount of hypochlorite solution required to treat one pipe volume with an initial chlorine dose of 300 mg/L can be calculated using the following equation:

$$\frac{300\frac{mg}{L}}{Conc_{soln}} * Vol_{main} = Vol_{soln} \qquad \text{(Eq. 13)}$$

where,

$Conc_{soln}$ = concentration of chlorine in a sodium hypochlorite solution, in mg/L as Cl_2, where 1 percent available chlorine solution is approximately equal to 10,000 mg/L.
Vol_{main} = volume of main, gal
Vol_{soln} = volume of sodium hypochlorite as chlorine solution, gal

Table 7 includes the minimum volumes of sodium hypochlorite solution (5 and 12.5 percent available chlorine) necessary to achieve an initial chlorine dosage of 300 mg/L in 100 ft. of main. Volumes in excess of the table values will be necessary because pumping must continue until the minimum chlorine dose is verified at the flushing outlet.

TABLE 7 - HYPOCHLORITE REQUIRED PER 100 FT OF MAIN

		Hypochlorite Solution				Hypochlorite Granules	
		gal of 5-percent		gal of 12.5-percent		ounces of 65-percent	
Pipe Size (in)	Total Pipe Volume (gal)	Dose 100 mg/L	Dose 300 mg/L	Dose 100 mg/L	Dose 300 mg/L	Dose 100 mg/L	Dose 300 mg/L
2	16.3	0.03	0.10	0.013	0.039	0.33	1.0
4	65.3	0.13	0.39	0.052	0.16	1.3	4.0
6	147	0.29	0.88	0.12	0.35	3.0	9.0
8	261	0.52	1.6	0.21	0.63	5.4	16.1
10	408	0.82	2.4	0.33	0.98	8.4	25.1
12	587	1.2	3.5	0.47	1.4	12.1	36.2
16	1044	2.1	6.3	0.84	2.5	21.4	64.3

Note: 5-percent chlorine solution = 50,000 ppm or mg/L free chlorine.

Addition of Premixed Solution

An alternate method is the preparation of a premixed chlorine solution in sufficient volume to completely fill the repaired section of main. A hypochlorite compound is added to potable water in a tanker truck or other large container in the proportions indicated in Table 7 to form a thoroughly mixed solution having a chlorine concentration of at least 300 mg/L. The chlorine solution from the tanker truck or large container is then pumped into the repaired section of the water main until the water main is full as indicated by a discharge through a hydrant or other outlet device at the other end of the section of water main being tested.

Minimum Contact Period

The minimum contact period for an initial chlorine dose of 300 mg/L is 15 minutes. After the minimum 15 minute contact period, a chlorine residual of at least 100 mg/L should be verified. Lower initial chlorine doses may be used for longer contact periods (e.g., 100 mg/L initial chlorine dose with a 3 hour contact time).

Final Steps

The heavily chlorinated water is flushed from the main until the chlorine residual is reduced to the level normally present in water supplied to the area. Consideration should be given to the collection of bacteriological samples after the disinfection procedure has been completed to provide a record of the effectiveness of the disinfection procedures where repairs were made under conditions that posed a threat of contamination.

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ATTACHMENT A

METHODS FOR MEASURING FREE CHLORINE RESIDUAL

Standard Methods for the Examination of Water and Wastewater (APHA *et al.*, 2005) describes eight methods for measuring residual chlorine concentration. Of the eight, the amperometric titration, DPD colorimetric, DPD ferrous titrimetric, and iodometric titration methods are the most commonly practiced. The amperometric titration method is the most common method of measurement practiced in the laboratory and the DPD colorimetric method is the most common and simplest method of measurement practiced in the field.

DPD colorimetric methods used in the field typically involve collecting a water sample in the sample tube of a DPD test kit; adding the DPD color reagent (N,N-diethyl-p-phenylenediamine) provided in the kit to the water sample; and then matching the resulting color of the sample with a color on the comparator wheel to estimate the free chlorine residual in mg/L. The magenta or red coloring of the sample can be observed as the DPD is oxidized by the free chlorine in the sample. The intensity of the color is directly proportional to the free chlorine concentration in the sample. DPD colorimetric field test kits for a variety of ranges of free chlorine are widely available.

Each DPD colorimetric chlorine test kit is designed to measure a specified range of free chlorine concentration. Low range test kits typically measure free chlorine concentrations as high as 3.5 to 5 mg/L. Some manufacturers have produced high range test kits that are capable of measuring free chlorine concentrations at the level of doses required for disinfection of water mains, e.g. 25 mg/L. A low range test kit can, however, be used to measure a free chlorine concentration higher than the kit's range by diluting the sample to reduce the free concentration to be within range of the test kit. Samples can be diluted using the graduated cylinder dilution method or the DPD drop dilution method.

It is important to note that if the concentration of chlorine in the sample exceeds the highest concentration for which a DPD test kit is valid, or if the reagents are not added in the proper order, the results are likely to be erroneous.

Graduated Cylinder Dilution Method

Collect a 2 mL sample of highly chlorinated water and pour the sample into an empty 50 mL or larger graduated cylinder. Add distilled water for a total of 50 mL and gently mix. Distilled water can be purchased in most grocery and convenience stores in gallon containers.

Transfer from the graduated cylinder the volume of diluted chlorinated water specified by the test kit to the test kit's sample tube. Add DPD reagent, mix, and then estimate the free chlorine concentration based on a comparison of the color of the diluted sample with the kit's standards according to the kit's instructions.

Multiply the estimated free chlorine concentration by the dilution factor, which is calculated as follows:

$$\frac{\text{(Volume of distilled water + Volume of chlorinated sample)}}{\text{(Volume of chlorinated sample)}} = \text{Dilution Factor} \quad \text{(Eq. A1)}$$

When 2 mL of sample are combined with 48 mL of distilled water in a graduated cylinder, the dilution factor is 25 as determined below:

$$\frac{\textbf{(48 mL of distilled water + 2mL of sample)}}{\textbf{(2mL of chlorinated sample)}} = \textbf{Dil. Factor of 25}$$

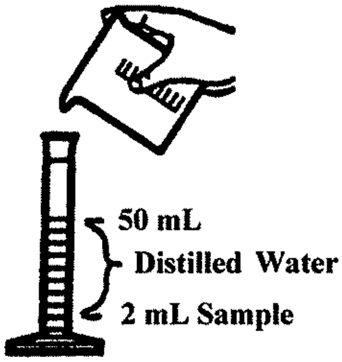

Figure A-1 Dilution of Sample in Graduated Cylinder.

For example, if it is determined that the diluted sample from the graduated cylinder has a chlorine residual of 1 mg/L, the undiluted sample from the disinfected main would have a residual of 25 x 1 mg/L or 25 mg/L. If it is not possible to accurately determine the chlorine residual of the undiluted sample, it may be necessary to apply a different dilution to the sample. For example, if the anticipated level of chlorine residual is around 100 mg/L, as it might be in for the slug method, a more appropriate dilution factor would be 50. This level of dilution could be obtained by diluting 1 mL of sample with 49 mL of distilled water.

DPD Drop Dilution Method

Add 10 mL of distilled water and one premeasured packet or powder pillow of DPD reagent (or 0.5 mL of DPD solution) to the DPD test kit's sample tube.

Using an eye dropper, add a sample of the highly chlorinated water on a drop-by-drop basis to the kit's sample tube until a color is produced.

Record the number of drops added to the sample tube. Assume one drop equals 0.05 mL.

Determine the free chlorine concentration in the kit's sample tube that contains the drops of sample, 10 mL of distilled water, and the DPD reagent by means of a colorimetric comparison with the standard according to the test kit's instructions.

Estimate the chlorine residual in the chlorinated sample from the disinfected main with the following equation:

$$\frac{(Cl_2\ \text{Residual}_{\text{sample-tube}},\frac{\text{mg}}{\text{L}})*(\text{Vol}_{\text{distilled-water}},\text{mL})}{(\text{Vol}_{\text{sample}},\text{drops})*(0.05\frac{\text{mL}}{\text{drop}})} = Cl_{2\ \text{residual-sample}},\frac{\text{mg}}{\text{L}} \qquad \text{(Eq. A2)}$$

For example, assume three drops of chlorinated water from the disinfected main determined a free chlorine concentration of 0.6 mg/L in 10 mL of distilled water in the kit's sample tube. Determine the free chlorine concentration in the sample of chlorinated water from the disinfected main with Eq. A2:

$$\frac{(0.6\ \text{mg/L})*(10\ \text{mL})}{(3\ \text{drops})*(0.05\ \text{mL/drop})} = 40\ \text{mg/L}$$

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ATTACHMENT B

BACTERIOLOGICAL SAMPLING AND ANALYSIS

AWWA C651-05 requires that two consecutive sets of samples, taken at least 24 hours apart, be collected from the main and examined for bacteriological contamination after the final flushing and prior to connecting the new main to the distribution system. If the results of the examination of the initial bacteriological samples are unsatisfactory, the new main should be flushed and additional samples collected and examined. According to AWWA C651-05, if the results of the examination of any of the additional samples are also unsatisfactory, the main must be re-chlorinated, flushed, and resampled until satisfactory results are obtained. KDHE recommends bacteriological testing of newly installed or repaired mains.

Analytical Methods

AWWA Standard C651-05 requires that the samples be examined for bacteriological quality in accordance with AWWA's *Standard Methods for the Examination of Water and Wastewater* (APHA *et al.*, 2005). Coliforms are the indicator organisms used in monitoring the bacteriological quality of drinking water. The maximum contaminant level for total coliforms under the Safe Drinking Water Act is based on the presence or absence of the indicator bacteria, not on density or direct count. Four commonly utilized laboratory methods of examination for coliforms are described in *Standard Methods for the Examination of Water and Wastewater*: MMO-MUG, multiple tube fermentation (MTF), presence-absence (PA), and membrane filtration (MF).

Several private laboratories located within the state of Kansas are certified for microbiological examination of drinking water samples. A current list can be obtained from the Public Water Supply Section of KDHE at (785) 296-5514, KDHE's Laboratory Improvement Program Office at (785) 296-3811 or http://www.kdheks.gov/lipo/index.html, or the KDHE district offices. The laboratory that is chosen to perform the analysis will typically provide the sampler with instructions and appropriate containers for sample collection. The KDHE microbiology laboratory is also available for examination of bacteriological samples. Scheduling for sample bottles and their examination by the KDHE microbiology laboratory may be requested from the Public Water Supply Section of KDHE at (785) 296-5514. Public Water Supply Systems that currently receive monthly sample bottles for monitoring distribution system samples for compliance with the Total Coliform Rule must not utilize their regular monthly bottle allotment for assessing the effectiveness of disinfection procedures on mains. Additional sample bottles requested for this sampling effort must be requested as a special project.

Number of Samples

AWWA Standard C651-05 provides that at least one set of samples for bacteriological examination be collected from every 1,200 ft of the new water main, plus one set from the end of the line, and at least one set from each branch. If trench water or excessive quantities of dirt entered the new main during construction, samples should be taken at intervals of approximately 200 ft and identified by location.

Sample Collection Procedures

Use only sterile bottles furnished by the laboratory. Keep the bottles sealed until used. Each sample bottle should contain a de-chlorinating agent (typically, sodium thiosulfate) in sufficient amount to neutralize any residual chlorine in the water sample. Do not rinse the bottle prior to taking the sample as such rinsing will remove the de-chlorinating agent and render the subsequent sample invalid. Samples are not to be taken from a sampling fixture that has an aerator attached or from a sampling fixture attached to pipe or pipe/hydrant combination having a weep hole.

C651-05 prohibits collection of samples from hoses or fire hydrants. Experience has shown that the examination of samples collected from these types of sampling locations may result in a false presence of coliforms due to contamination of the sample. AWWA Standard C651-05 recommends the use of a specially installed sampling tap consisting of a smooth, unthreaded, 0.5-inch hose bib. Alternatively, a corporation stop installed in the main equipped with a copper-tube gooseneck assembly may be utilized as a sampling tap. After the samples have been collected, the gooseneck assembly may be removed and retained for future use.

Be sure that the heavily chlorinated water has been thoroughly flushed from the main before sampling. Run water through the sampling tap at a steady rate 3 to 5 minutes before beginning sampling procedure.

Wash hands thoroughly. Remove the bottle lid just before filling, holding the lid in your free hand. Do not contaminate the inner surface of the cap of the bottle with your hands. Fill the bottle to the shoulder or fill line. Do not overflow the bottle or splash water into or out of the bottle or onto the outside rim of the bottle. Replace the lid and tighten securely.

Complete the appropriate sample documentation provided by the laboratory. This will typically include a sample label and chain of custody form. If the KDHE laboratory is being utilized, a KDHE Sampling Data Card must be completed instead of a chain of custody form. The KDHE Sampling Data Card requires completion of the following information: collection date, collector's last name and first initial, time of collection, collection location, and chlorine residual.

Sample Delivery to Laboratory

Deliver the samples to the laboratory promptly after collection. There are strict time limits on the amount of time that may elapse between sample collection and analysis before the sample is considered too old to analyze. Check with your laboratory on sample holding time requirements. The EPA requires that samples reach the laboratory within 30 hours of collection. Unless special arrangements are made, schedule the collection of samples so that they do not arrive at the laboratory on weekends or holidays. Samples should be held at a temperature of 40 °F (4°C). If practicable, place samples in an iced cooler for storage during transport if transport time will exceed one hour. At no time, however, should the sample container be allowed to become immersed or submerged in the ice or melted ice water. Check with the laboratory for specific packaging and transport recommendations.

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ATTACHMENT C

EXAMPLE CALCULATIONS FOR THE DISINFECTION OF WATER MAINS WITH CHLORINE

1. **FLUSHING RATE – Calculate the flushing rate for a given velocity (Table 1).**

Example:

Calculate the flushing rate for a 6-inch diameter pipe which would provide a velocity of 2.5 ft/sec within the main.

Formulas:

$Area_{main}$, $ft^2 = \pi[(dia, ft)^2/4]$ = cross-sectional area of main

Flushing rate, gpm
= ($Area_{main}$, ft^2)*(Velocity, ft/sec)*(7.48 gal/ft^3)*(60 sec/min)

Solution:

$Area_{main}$, $ft^2 = \pi[(6\text{ in})*(1\text{ ft}/12\text{ in})]^2/4 = 0.196\text{ ft}^2$

Flushing rate, gpm
= (0.196 ft^2)*(2.5 ft/sec)*(7.48 gal/ft^3)*(60 sec/min)
= 220 gpm

2. **PREPLACEMENT OF HTH GRANULES IN MAIN – Calculation of the amount of calcium hypochlorite (HTH) granules required for disinfection of a water main with a chlorine dose of 25 mg/L (Table 3).**

Example:

Calculate the quantity of calcium hypochlorite granules required to disinfect 1,000 feet of a 4-inch diameter PVC pipe. Assume granules contain 65 percent available chlorine by weight.

Formulas:

Vol_{main}, MG = π(dia, ft)^2/4*(length, ft)*(7.48 gal/ft^3)*(1 MG/1x10^6 gal)

Cl_2 needed, lb = (Vol, MG)*(Cl_2 dose, mg/L)*(8.34 lb/gal)

Calcium hypochlorite needed, lb = (Cl_2 needed, lb)/(percent available Cl_2/100)

Solution:

Vol_{main}, MG = π[(4 in)*(1 ft/12 in)]^2/4*(1,000 ft)*(7.48 gal/ft^3)*(1 MG/1x10^6 gal)
= 0.000653 MG

Calcium hypochlorite needed for disinfection of 1,000 ft of 4-in pipe, oz
= (0.000653 MG)*(25 mg/L Cl_2)*(8.34 lb/gal)*(16 oz/lb)/(0.65)
= 3.4 oz

This answer could also be obtained from Table 3 which is expressed in terms of the ounces of calcium hypochlorite granules required each 500-foot interval. In this example, since the pipe is 1,000 feet long, the amount of granules required must be doubled so the amount needed is 2 * 1.7 oz = 3.4 oz.

3. **PREPLACEMENT OF HTH TABLETS IN MAIN – Calculation of the number of 5-g calcium hypochlorite tablets (65 percent available chlorine) for disinfection of a water main with an initial chlorine dose of 25 mg/L (Table 4).**

Example:

Calculate the number of 5-g calcium hypochlorite tablets (65 percent available chlorine) necessary to apply an initial chlorine dose of 25 mg/L to 846 feet of 8-inch diameter PVC pipe.

Formulas:

Vol_{main}, MG = π[(dia, ft)^2/4]*(length, ft)*(7.48 gal/ft^3)*(1 MG/1x10^6 gal)

Calcium hypochlorite needed, lb
= (Vol, MG)*(Cl_2 dose, mg/L)*(8.34 lb/gal)/(percent available Cl_2/100)

Solution:

Vol_{main}, MG = π[(8 in)*(1 ft/12 in)]^2/4*(846 ft)*(7.48 gal/ft^3)*(1 MG/1x10^6 gal)
= 0.00221 MG

Calcium hypochlorite needed for disinfection of 846 ft of 8-in pipe, lb
= (0.00221 MG)*(25 mg/L Cl_2)*(8.34 lb/gal)/(65%/100)
= 0.71 lb

Weight per 5-g tablet of calcium hypochlorite, lb/tablet
= (5 g/tablet)*(0.035274 oz/g)*(1 lb/16 oz)
= 0.011 lb/tablet

Number of tablets providing 0.71 lb of calcium hypochlorite, tablets
= (0.71 lb calcium hypochlorite)*(1 tablet/0.011 lb)
= 64.5 tablets

Since there are approximately 47 sections of 18-foot sections in an 846-foot length of main, the number of tablets required per 18-foot section is 64.5 tablets/47 sections = 1.37 tablets per section. Assuming partial tablets are not possible, 2 tablets should be used per section of pipe for a total of 94 tablets for the 846 ft length of pipe. As Table 4 indicates, this solution could also be obtained from 2 tablets for each 18-foot section of 8-inch pipe.

4. CONTINUOUS METHOD

Procedure 1: Addition of Premixed Chlorinated Water (Table 5)

Example:

Calculate the amount of hypochlorite (sodium or calcium) necessary for disinfection of 500 ft of 6-inch main by the addition of premixed chlorinated water. For this problem, assume calcium hypochlorite is 65 percent available chlorine and sodium hypochlorite is a 15 percent available chlorine solution.

Formulas:

Vol_{main}, MG = $\pi[(\text{dia, ft})^2/4]*(\text{Length, ft})*(7.48\ \text{gal/ft}^3)*(1\ \text{MG}/1\text{x}10^6\ \text{gal})$

Utilizing calcium hypochlorite,
lbs of HTH = (Vol_{main}, MG)*(8.34 lb/gal)*(25 mg/L Cl_2)/(percent available Cl_2/100)

Utilizing sodium hypochlorite,
minimum volume, gal = (Vol_{main})*(25 mg/L Cl_2)/($Conc_{soln}$, mg/L as Cl_2), where a 1 percent available chlorine solution as sodium hypochlorite is approximately equivalent to 10,000 mg/L as Cl_2.

Solution:

Vol_{main}, MG = $\pi[(6/12)^2/4]*(500\ \text{ft})]*(7.48\ \text{gal/ft}^3)*(1\ \text{MG}/1\text{x}10^6\ \text{gal})$
= 7.34×10^{-4} MG or 734 gal

Utilizing 65 percent available chlorine calcium hypochlorite, the required amount of HTH in lbs to be added to 734 gal:

= (7.34×10^{-4} MG)*(8.34 lb/gal)*(25 mg/L Cl_2)/(0.65)
= 0.24 lb or 3.8 oz

The volume of 15 percent available chlorine sodium hypochlorite to be added to 734 gallons:

$$= (734 \text{ gal})*(25 \text{ mg/L } Cl_2)/(150{,}000 \text{ mg/L})$$
$$= 0.12 \text{ gal}$$

This answer can also be obtained from Table 5 which indicates that for a 100-foot section of 6-inch diameter water main, 0.024 gal of 15 percent available chlorine sodium hypochlorite or 0.75 ounces of 65 percent available chlorine HTH are required for a 25 mg/L chlorine dose. Since the problem statement specifies a 500-foot main, the table entries should be multiplied by 5 yielding the minimum quantities of 0.12 gal of 15 percent available chlorine sodium hypochlorite or 3.8 oz of 65 percent available chlorine HTH.

Procedure 2: Injection of Concentrated Chlorine Solution (Table 5)

Example:

Calculate the amount of hypochlorite (sodium or calcium) necessary for disinfection of 5,250 ft of 8-inch diameter main by the continuous method. For this problem, assume calcium hypochlorite is 65 percent available chlorine and sodium hypochlorite is a 15 percent available chlorine solution.

Formulas:

$$Vol_{main}, \text{MG} = \pi[(\text{dia, ft})^2/4]*(\text{length, ft})]*(7.48 \text{ gal/ft}^3)*(1 \text{ MG}/1\text{x}10^6 \text{ gal})$$

Chlorine feed rate ($Cl_{2\ feed}$), lb/hr

$$= (Q_{fill}, \text{gpm})*(1440 \text{ min/day})*(1 \text{ day/24 hr})*(1 \text{ MG}/1\text{x}10^6 \text{ gal})*(25 \text{ mg/L})$$

Calcium Hypochlorite

$$\text{Calcium hypochlorite, lb/hr} = (Cl_{2\ feed}, \text{lb/hr})/(\text{percent available } Cl_2/100)$$

$$\text{HTH, in lb} = (Vol_{main}, \text{MG})*(8.34 \text{ lb/gal})*(25 \text{ mg/L } Cl_2)/(\text{percent available } Cl_2/100)$$

Chlorine concentration in prepared chlorine solution, mg/L

$$= (\text{HTH, lb})/(Vol_{soln})* (1\text{x}10^6 \text{ gal/1 MG}) *(1 \text{ mg/L}/8.34 \text{ lb/MG})*(\text{percent available } Cl_2/100)$$

Sodium Hypochlorite

Flow rate of water into main (Q_{fill}), gpm

$$= [(Conc_{soln}) * (Q_{soln}, \text{gpm})/25 \text{ mg/L})] - (Q_{soln}, \text{gpm})$$

Solution:

Vol_{main}, MG = $\pi[(8\text{ in})*(1\text{ ft}/12\text{ in})]^2/4]*(5{,}250\text{ ft})*(7.48\text{ gal/ft}^3)*(1\text{ MG}/1\text{x}10^6\text{ gal})$
= 0.0137 MG

Calcium Hypochlorite

Assume a chlorine solution injection rate of 2.5 gal/hr (0.0417 gpm) and a filling rate of 150 gpm.

Cl_2 feed rate, lb/hr
= (150 gpm)*(1440 min/24 hr)*(1 MG/1x10^6 gal)*(8.34 lb/gal)*(25 mg/L)
= 1.88 lb/hr

Calcium hypochlorite feed rate, lb/hr
= (1.88 lb/hr)/(65%/100)
= 2.89 lb/hr

Calcium hypochlorite necessary for disinfection of 5,250 ft of main, lb
= (0.0137 MG)*(25 mg/L Cl_2)*(8.34 lb/gal)/(65%/100)
= 4.4 lb

The time it takes to fill the main, T_{fill}, which may be assumed equivalent to the period of chlorine solution injection, $T_{injection}$, is determined by dividing the volume of the main by the rate of filling: 13,700 gal/150 gpm = 91 min. For a chlorine solution injection rate, Q_{soln}, of 0.0417 gpm, the required volume of chlorine solution, Vol_{soln}, is 3.8 gal. The combination of 4.4 lb of HTH in 3.8 gal of water results in a chlorine solution with a concentration estimated by the following:

Chlorine concentration in solution, mg/L as Cl_2
= (4.4 lb/3.8 gal)*(65%/100)*(1x10^6 gal/1 MG)*(1 mg/L/8.34 lb/MG)
= 90,200 mg/L or an approximately 9% solution.

Sodium Hypochlorite

In this case, assume the 15 percent available chlorine sodium hypochlorite solution will be pumped into the main without dilution at an injection rate of 2.5 gal/hr (0.0417 gpm). The required main filling rate, Q_{fill}, can be calculated as follows:

Q_{fill}, gpm = [(0.0417 gpm)*(150,000 mg/L)]/(25 mg/L) – 0.0417 = 250 gpm
The required volume of sodium hypochlorite solution is calculated from $T_{injection}$ and the assumed injection rate:

T_{fill}, min = $T_{injection}$, min = 13,700 gal/250 gpm = 55 min

Vol_{soln}, gal = (55 min)*(0.0417 gpm) = 2.3 gal

An alternative approach is to calculate the required feed rate of sodium hypochlorite. For an assumed main filling rate of 150 gpm (Q_{fill}), a 15 percent available chlorine solution, and an injection rate of 2.5 gal/hr (0.0417 gpm), the sodium hypochlorite feed rate (Na-$hypo_{feed}$) to form a 25 mg/L chlorine dose is calculated from the following equation:

Sodium hypochlorite feed rate (15 percent available chlorine), lb/hr
= [(150 gpm)*(1440 min/day)*(1 day/24 hr)*(1 MG/1x10^6 gal)
(8.34 lb/gal)(25 mg/L Cl_2)]/(15%/100)
= 12.5 lb/hr

Sodium hypochlorite feed rate (15 percent available chlorine), gal/hr
= [(150 gpm)*(1440 min/day)*(1 day/24 hr)*(1 MG/1x10^6 gal)
*(25 mg/L Cl_2)]/(15%/100)
= 1.5 gal/hr

T_{fill}, min = $T_{injection}$, min = 13,700 gal/150 gpm = 91 min

$Vol_{Na\text{-}hypo}$, gal = (91 min)*(0.0417 gpm) = 3.8 gal of sodium hypochlorite

Sodium hypochlorite, lb
= (12.5 lb/hr)*(91 min)*(1 hr/60 min)
= 18.9 lb

Sodium hypochlorite, gal
= (1.5 gal/hr)*(91 min)*(1 hr/60 min)
= 2.3 gal

5. SLUG METHOD – Calculation of the amount of chlorine necessary to form a slug of chlorinated water in a main with an initial chlorine dose of 100 mg/L.

Example:

Calculate the amount of chlorine gas required to create a slug of chlorinated water in 5,000 ft of a 6-inch diameter ductile iron main with an initial chlorine dose of 100 mg/L.

Formulas:

Vol, MG
= π[(dia, ft)^2/4]*(length of "slug", ft)*(7.48 gal/ft^3)*(1 MG/1x10^6 gal)

Chlorine (100 percent available chlorine) needed, lb
= (Vol, MG)*(Cl_2 dose, mg/L)*(8.34 lb/gal)

Solution:

Vol_{main}, MG
$= (\pi[(16 \text{ in})*(1 \text{ ft}/12 \text{ in})]^2/4)*(5{,}000 \text{ ft})*(7.48 \text{ gal/ft}^3)*(1 \text{ MG}/1\text{x}10^6 \text{ gal})$
$= 0.0522$ MG

Chlorine (100 percent available chlorine) needed, lb
= (0.0522 MG)*(100 mg/L)*(8.34 lb/gal)
= 43.5 lb

6. **EMERGENCY MAIN DISINFECTION – Calculation of the sodium hypochlorite pumping rate and minimum volume of hypochlorite necessary to establish initial chlorine doses of 100 mg/L and 300 mg/L in a water main (Table 7).**

Example:

Calculate the sodium hypochlorite pumping rate (assuming a 5 percent available chlorine solution) and the amount of sodium hypochlorite solution necessary to establish a 300 mg/L chlorine dose in a 300-foot section of a 6-inch diameter main. Assume Q_{fill} into the main is 50 gpm.

Formulas:

Sodium hypochlorite solution pumping rate, gpm
$= [(Cl_2 \text{ dose, mg/L})/(Conc_{soln}, \text{ mg/L})]*(Q_{fill}, \text{ gpm})$

Vol_{main}, gal
$= (\pi(\text{dia, ft})^2/4)*(\text{Length, ft})*(7.48 \text{ gal/ft}^3)$

Volume of sodium hypochlorite solution, gal
$= [(Cl_2 \text{ dose, mg/L})/(Conc_{soln}, \text{ mg/L})]*(Vol_{main}, \text{ gal})$

Solution:

Sodium hypochlorite solution pumping rate, gpm
$= [(300 \text{ mg/L } Cl_2)/(50{,}000 \text{ mg/L } Cl_2)]*(50 \text{ gpm})$
= 0.3 gpm

Vol_{main}, gal
$= (\pi[(6 \text{ in})*(1 \text{ ft}/12 \text{ in})]^2/4)*(300 \text{ ft})*(7.48 \text{ gal/ft}^3)$
= 441 gal

Volume of sodium hypochlorite solution, gal
$= [(300 \text{ mg/L } Cl_2)/(50{,}000 \text{ mg/L})]*441$ gal
= 2.65 gal

$T_{injection}$, min = 2.65 gal/0.3 gpm = 441 gal/50 gpm = 8.8 min

The volume of sodium hypochlorite solution calculated in this problem can also be determined from Table 7. Table 7 indicates for a 6-inch pipe, 0.88 gal of 5-percent sodium hypochlorite solution is required to establish a 300 mg/L dose of Cl_2 in a 100-ft section of main. For a 300-ft section of main, the necessary volume of sodium hypochlorite from Table 7 for a 100-ft section should be multiplied by 3 to give 2.6 gal.